

I. Abstract

Several devices have been developed to convert the wave energy into electricity and they can be found in different degrees of development. A very interesting group of wave energy converters (WEC) is composed of direct drive systems which are characterized by having a simpler mechanical structure compared to others. For example, in the Archimedes Wave Swing (AWS) and the Uppsala/Seabed AB WEC, the Power Take-Off (PTO) system is composed of a linear permanent magnet synchronous generator (PMSG). Due to the nature of the ocean waves, this electricity presents high variability both in amplitude and in frequency. For this reason, direct drive systems require power electronics to convert this very irregular electricity into a form suitable for the grid connection. This work is focused on the WEC modeling in time-domain and, taking advantage of the electronic converter, on maximizing the captured power.

II. WEC Model

The WEC under study in this work is a point absorber consisting of a cylindrical buoy limited to heave motion and rigidly connected to a PTO system (a linear PMSG) on the seabed. The motion of the buoy with one DoF can be described by the Cummins equation:

$$[m + A(\infty)] \cdot \ddot{y}(t) + \int_{-\infty}^t k_r(t - \tau) \cdot \dot{y}(\tau) d\tau + \rho g S_w \cdot y(t) = f(t)$$

➤ Fluid memory equation:

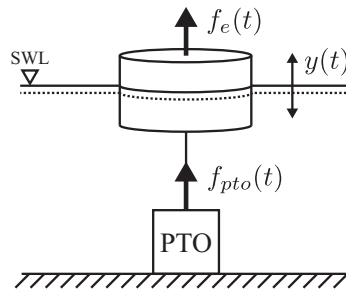
$$k_r(t) = \int_0^\infty B(\omega) \cos(\omega t) d\omega$$

➤ External forces on the buoy:

$$f(t) = f_e(t) + f_{pto}(t)$$

➤ Excitation force by the incoming wave:

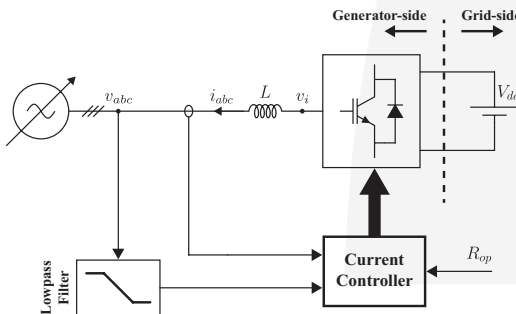
$$f_e(t) = \int_{-\infty}^\infty k_e(t) \zeta(t - \tau) d\tau$$



IV. Control Implementation

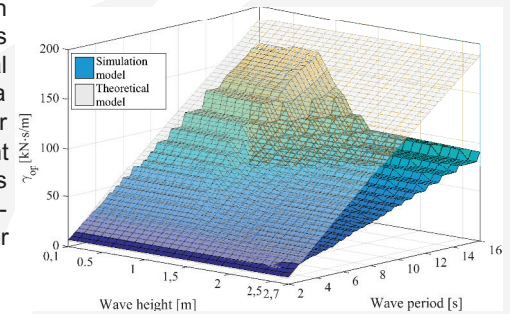
The optimal power point can be achieved by emulating a resistive load connected to the linear PMSG that is related to the optimal damping coefficient. Thus, a three-phase ac-dc boost-rectifier is implemented. The voltages at the generator terminals are measured and divided by the optimal resistance for a given sea state resulting in current reference signals. Note that the current reference is in phase with the measured voltage, so the impedance seen by the linear PMSG is purely resistive. To emulate the resistive load, three current controllers have been applied and their performance assessed: 1) Hysteresis-band controller; 2) Space-Vector PWM controller; and 3) Spatial hysteresis current source.

It is important to note that the low-pass filter plays a key role in the system. In addition, the boost-rectifier has been modeled taking into account the switching losses to assess its efficiency.



III. Optimal Power Point

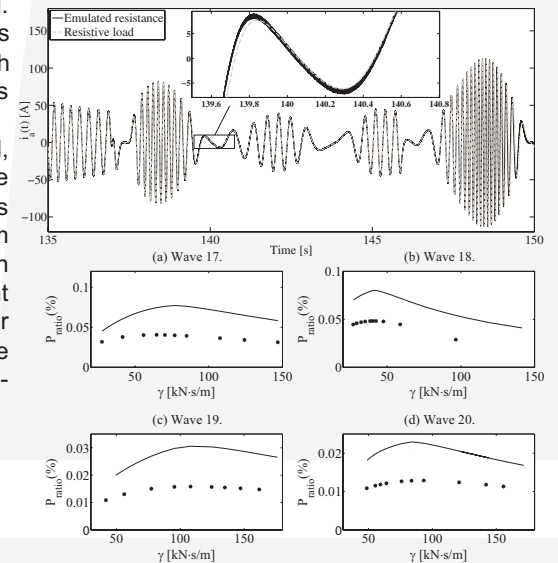
The PTO force is the electromagnetic force generated by the the PMSG. This force opposes to the motion as a damping force with a damping coefficient that is proportional to the translator speed and related to a resistance. So, the proposed control strategy is to maximize the power extraction for each sea state. Thus, the system has been tested with several regular waves to identify an optimal damping (related to a resistive load) for each set of height and period. This relationship is dependent on the generator characteristics.



V. Results

All of the three controllers present a very good dynamic response. However, the low-pass filter must be designed so that it does not introduce a large phase-shift into the measured voltage. The hysteresis-band control presents the best efficiency. On the other hand, the control strategy to maximize the captured power proved to be valid.

The system has been tested with irregular waves mathematically generated and, then, with wave data series measured from real seas. Both scenarios present the optimal power point around the optimal resistance.



VI. Publications

- Mendonça, H., and Martinez, S. "A Resistance Emulation Approach to Optimize the Wave Energy Harvesting for a Direct Drive Point Absorber." *Sustainable Energy, IEEE Transactions on* 7.1 (2016): 3-11.
- Martinez, S., Sanchez, J. A., Mendonça, H., Alvaro, R., Cuesta, A. and Diez, A. "Impact of a wave energy farm connected to a distribution grid in voltage power quality." 2013 CIGRÉ Lisbon Symposium. Lisbon, Portugal, Abr. 22-24, 2013.
- Mendonça, H., and S. Martinez. "Modeling of a wave energy converter connected to a resistive load." 2013 4th International Youth Conference on Energy (IYCE). Siófok, Hungary, Jun. 6-8, 2013.
- Mendonça, H., S. Martinez., and Ramirez, D. "Comparison of current control strategies applied to a boost-rectifier connected to a direct drive wave energy converter." 2015 International Conference on Renewable Energy Research and Application (ICRERA). Palermo, Italy, Nov. 22-25, 2015.
- Mendonça, H., and S. Martinez. "Energy Conversion Efficiency Assessment of a Direct Drive Wave Energy Converter with Different Current Controllers." 2016 IEEE International Energy Conference (ENERGYCON). Leuven, Belgium, Apr. 4-8, 2016.